



CHALLENGES AND PAYOFF OF COMPOSITES IN TRANSPORT AIRCRAFT:
777 EMPENNAGE AND FUTURE APPLICATIONS

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52-24
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FIGURE

TITLE PAGE1. 777 AIRPLANE

The Boeing 777 is the first of a new family of wide body airplanes. The new large twin is sized to accommodate 360 to 390 passengers in typical two-class configurations and planned growth beyond that. The 777 offers airlines three engine options, extremely attractive operating costs, and compatibility with existing airport gates and taxiways. The 777 has a wingspan of nearly 197 feet and is offered with a wing-tip folding mechanism that will reduce the span to 156 feet.

2. COMPOSITES

Extensive use of advanced composites is included in the 777. The applications range from fiberglass fairings to primary structures. Flight control surfaces such as the elevators, rudder and flaps continue the composite design technology established with the 767 and 757. The use of composites is approximately 9% of the structural weight of the 777. This is nearly three times the amount used on previous Boeing transports. Expressed differently, the 777 has nearly 10 times the mass of composites as does the 757.

3. COMPOSITE EMPENNAGE

The 777 empennage includes the vertical fin and a horizontal stabilizer. Each consists of a structural box, an auxiliary or forward torque box, leading edges, tip, fixed trailing edges, elevator or rudder and body gap covers. The structural boxes are manufactured in carbon fiber reinforced plastic (CFRP). The primary structural box configuration is a two-spar, multirib design. The panels are attached to the ribs and spars using mechanical fasteners.

4. TOUGHENED MATERIAL

The material used for the empennage is a new, toughened epoxy material. The material provides outstanding resistance to impact damage. This slide compares the impact damage area of the conventional materials with the toughened material. As measured by damage area, the new material is nearly seven times better than the current production materials.

5. SKIN PANEL

The basic CFRP skin panel incorporates an integral I-section stiffened design. The panels are full span and are joined at the airplane centerline (horizontal stabilizer).

6. RIBS

The majority of the ribs are of a sandwich design using aramid honeycomb core and CFRP face sheets. The slide shows one of the more highly loaded ribs which is fully shear-tied and has mechanically attached chords.

7. SPARS

The CFRP spars are simple channel sections. The rear spar is a single piece with mechanically attached stiffeners, while the front spar is two pieces to allow for manufacturing payoff.

8. VOICE OF THE CUSTOMER

We have spent a great deal of effort on the 777 talking with and listening to our customers. We have worked together to develop the functionality and maintainability they desire. Our airline customers tell us we are doing a great job in meeting our commitments. Our composite service experience has been very good. Questions relating to composites usually came down to two:

How do you inspect it:, and
How do you repair it?

Our plan is use periodic visual inspection for all composite structures, with tools in the existing inventory as referees should a sign of distress occur.

9. REPAIR

The airlines do not give our industry especially high marks for existing composite repair methodologies. We have probed these concerns and have designed the 777 primary laminate structures to accommodate bolted repairs, much like metal structure. The repair is designed to be installed from one side, that is, access to the interior of the box is not required. This slide illustrates the skin side of an instrumented test panel prior to test. The completed repair meets all structural requirements as demonstrated by large panel and full scale structural box testing.

10. 777 EMPENNAGE TEST PLAN

A key milestone in the 777 program was reaching agreement with the certifying agencies as to the empennage certification plan. This milestone was achieved in November 1991. The test plan covers coupons, structural details, structural elements, subcomponents and a developmental test box.

The developmental test box was designed and fabricated using the materials, design concepts and manufacturing approach to be used for the 777. This test article is currently undergoing its planned second life of fatigue testing. This approach will provide the necessary substantiating data in a manner timely to support program schedules.

11. T-TAIL CFRP HORIZONTAL STABILIZER TEST COMPONENT

The success of this approach in providing the necessary test data was developed on the NASA/Boeing 737 horizontal stabilizer program. More recently, a generic T-tail horizontal stabilizer developmental program was patterned after this "building block" approach.

The T-tail horizontal stabilizer test article was subjected to the rigors of testing typical of that required for the certification of composite primary structure. This included a series of limit load tests, a two lifetime fatigue test with major damage, damage tolerance testing, repair and a final destruction test. Final failure occurred as predicted at an easily visible impact damage site after sustaining 166% DLL.

12. DESIGN FOR PRODUCIBILITY

Having the necessary technical data is only part of the equation. A key feature of any composite design is cost. The 777 empennage was designed with automation in mind. We began with a concept of how we wanted to assemble the structure. Final assembly occurs with complete access to the internal structure. The mechanic can stand in any rib bay during final close out.

Having determined the assembly plan, we designed the details to achieve a high penetration of automation. Our goal was to minimize touch labor operations, a large recurring cost driver. It was necessary to simplify the detail design to achieve our goal of automated production.

13. PANEL DESIGN

The panels were designed with automated tape laying equipment in mind. The basic skin plies are relatively simple, doublers inserted as packages. This approach permits all or nearly all of the panel to be laid up by machine.

14. SPARS

The spars are designed as simple constant sections. No padups are required at the spar chord or around the access holes. The front spar is a two piece design to accommodate manufacturing access during closeout.

15. TOOLING

Production tooling uses INVAR to minimize part warpage due to differences in thermal coefficients of expansion and provide the durability of a metal tool. The horizontal stabilizer skin LM is the largest layup tool.

16. SKIN LAYUP

Preproduction verification tests are demonstrating that the manufacturing plan works before production of parts begins. Here plies are being laminated by machine for a preproduction and tool proof 777 Horizontal Stabilizer skin panel.

17. DEMONSTRATION PANEL

The preproduction demonstration panel met all program objectives. First part production began on May 5, 1992 with the fabrication of the first stringer for the 777 horizontal stabilizer.

18. 777 STATUS

The 777 represents a major commitment to composite primary structure. The program is on schedule and is meeting its weight target. The weight reduction projected for the 777 horizontal stabilizer box is in excess of 20% when compared with a modern aluminum design.

19. THE FUTURE OR WHAT'S COMING NEXT!

Dr. Davis requested that I say a few words about the future use of CFRP for commercial aircraft.

We all know that composites are a technology which offers both a performance improvement and a weight reduction. Composite materials will permit subsonic transports to use less fuel operate more efficiently and increase payload/range capability. For supersonic transports, composite materials are crucial to building an aircraft that can withstand the heat of high-speed flight. However, the most significant hurdle facing these potentialities is COST! If we cannot reduce the cost of composites, it may be that none of these developments will occur.

20. WING COST EXAMPLE

Let me share with you an actual example of a composite wing and some of the cost reduction opportunities available. In the example shown, all aspects of design, tooling and manufacturing cost more than the metal wing counterpart.

In the non-recurring area, engineering design costs are higher--primarily due to increased analysis requirements (to say nothing of testing).

Tooling costs are higher, even though the total tool count is approximately one-third of that required for a metal wing. Recurring manufacturing costs were higher in all areas-- detail fabrication, minor

assembly and major assembly. As expected, material costs are also higher. Clearly there is ample opportunity to address costs in each of these areas. If we are to reduce costs significantly, it will not be sufficient to focus on just one arena. All aspects of cost must be addressed-- Design, Tooling, Manufacturing, Quality and Materials.

21. GROWTH EXAMPLE

A potentially serious constraint for composites occurs when one considers the airplane growth typical for a modern jet transport. Increases in airplane gross weight often require strengthening component parts. Composite tooling concepts and designs must recognize this. Tooling concepts must be flexible enough to handle late design changes, capable of supporting demanding tool design and fabrication schedules and robust enough to handle airplane growth without major investments in retooling. The so-called "single-shot cure" may well be the answer for parts and assemblies not subject to late design load changes or subsequent derivative aircraft development, but such approaches may well be too costly for a large transport in rate production with multiple derivatives on a common production line.

22. SUMMARY

Composites have achieved significant performance benefits:

- reduced weight
- corrosion free structure
- durable structure

Our challenge is to reduce the cost of composite aircraft structures. No program will be successful if it does not deliver the right product at the right time for the right cost. The inescapable connection is that the research we do now will determine our capabilities for the next century.

NASA has gained world renown in the international aviation industry and academia for broadening the frontiers and understanding of aeronautics with the outflow of NASA technology research to all. NASA has been among the leaders in the development of advanced material technologies. But technology is just one of the fronts we must address to remain competitive. Research into what makes a better factory is necessary if we are to bring high quality goods to the market quickly at competitive prices. These advances must be made if advanced composites are to increase their penetration in transport structural applications.

I am pleased that you are addressing these issues now at conferences such as this.

Thank you.

BOEING 777



Figure 1



Figure 2

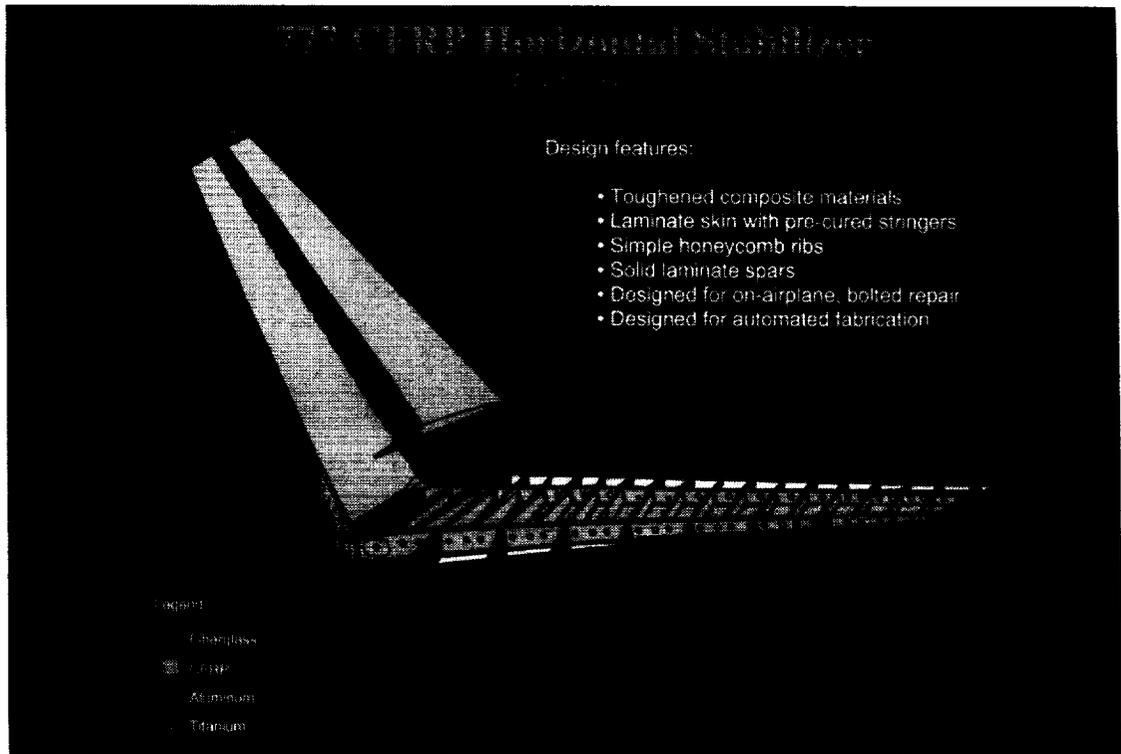


Figure 3

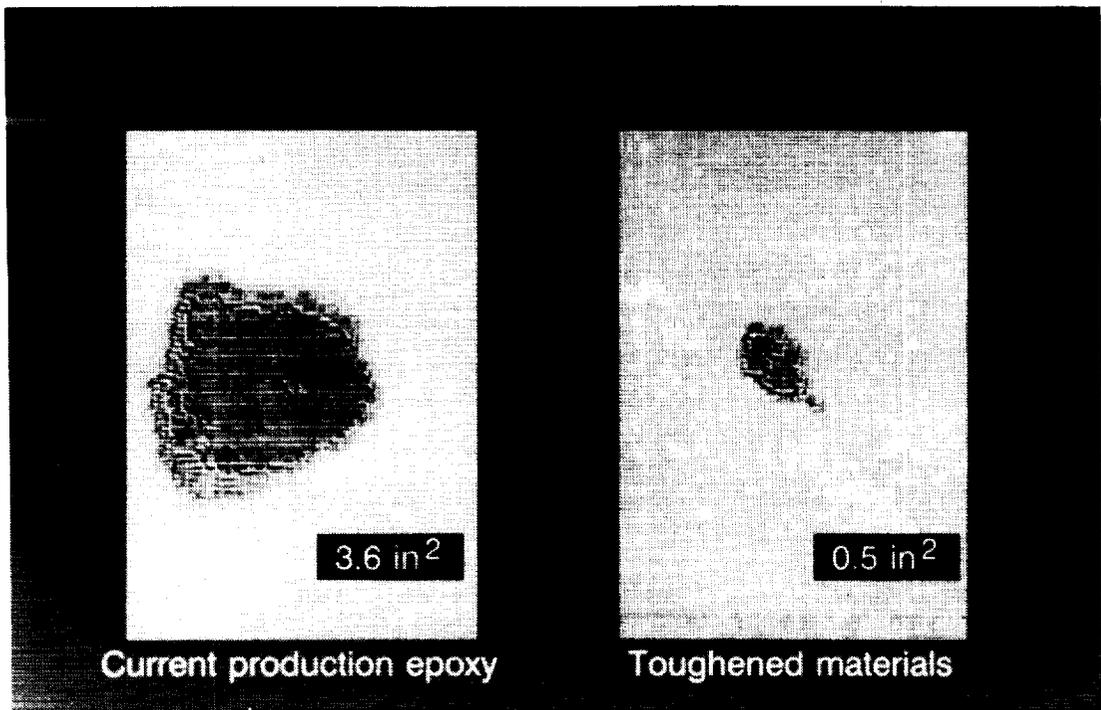


Figure 4

777 Horizontal Stabilizer Main Box Skin Panels

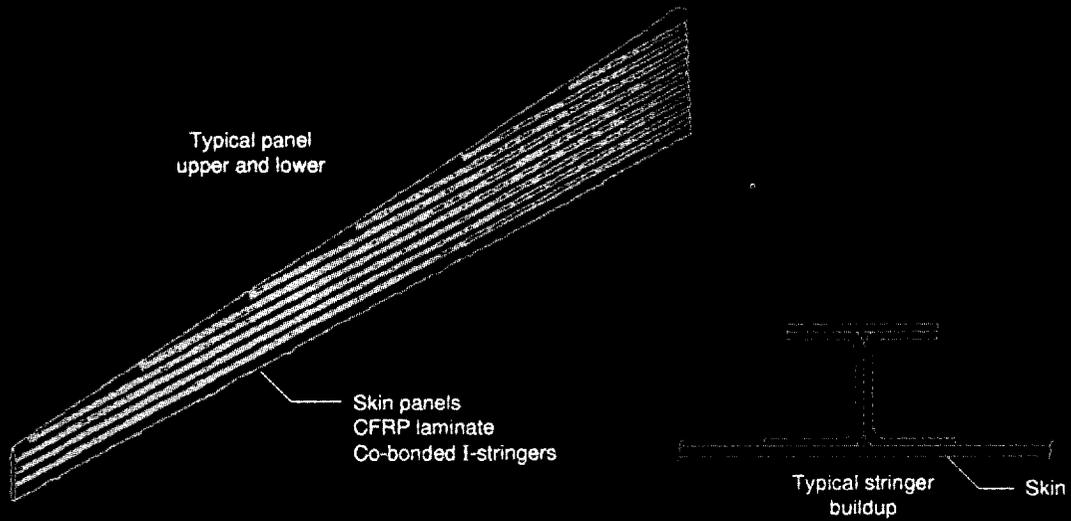


Figure 5

777 Horizontal Stabilizer

Ribs No. 3 Through No. 10

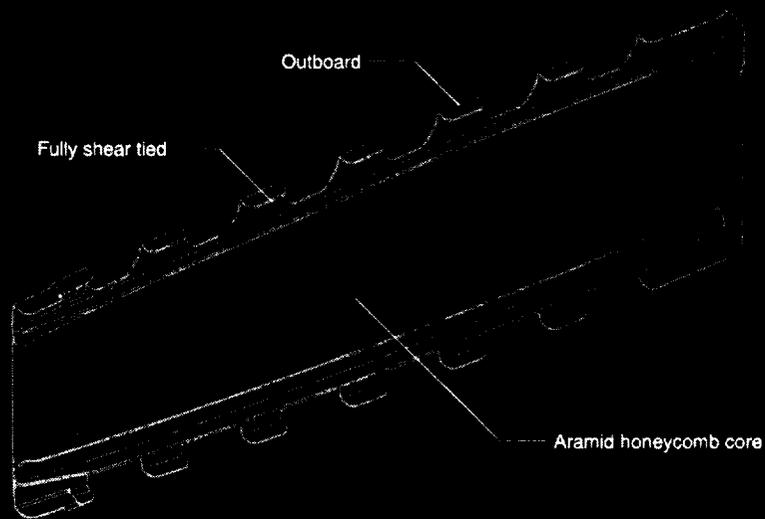


Figure 6

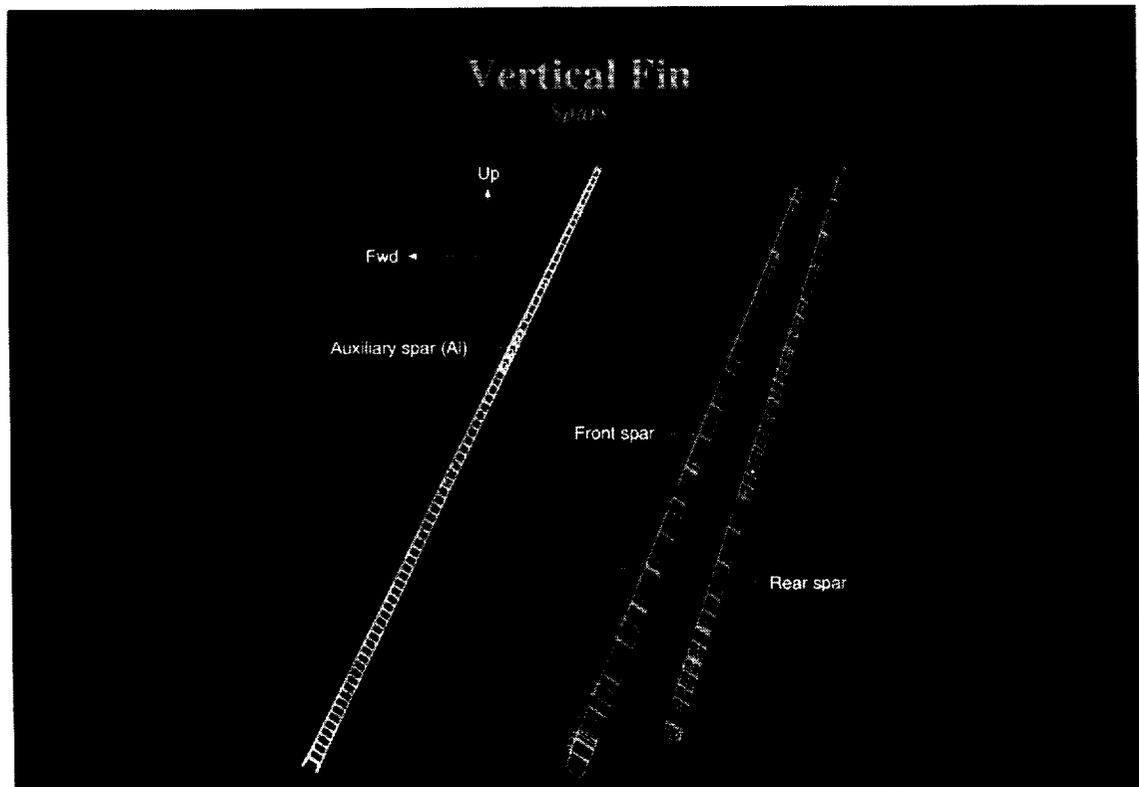


Figure 7

The Voice of the Customer

- How do you inspect it?
- How do you repair it?

Figure 8

REPAIR

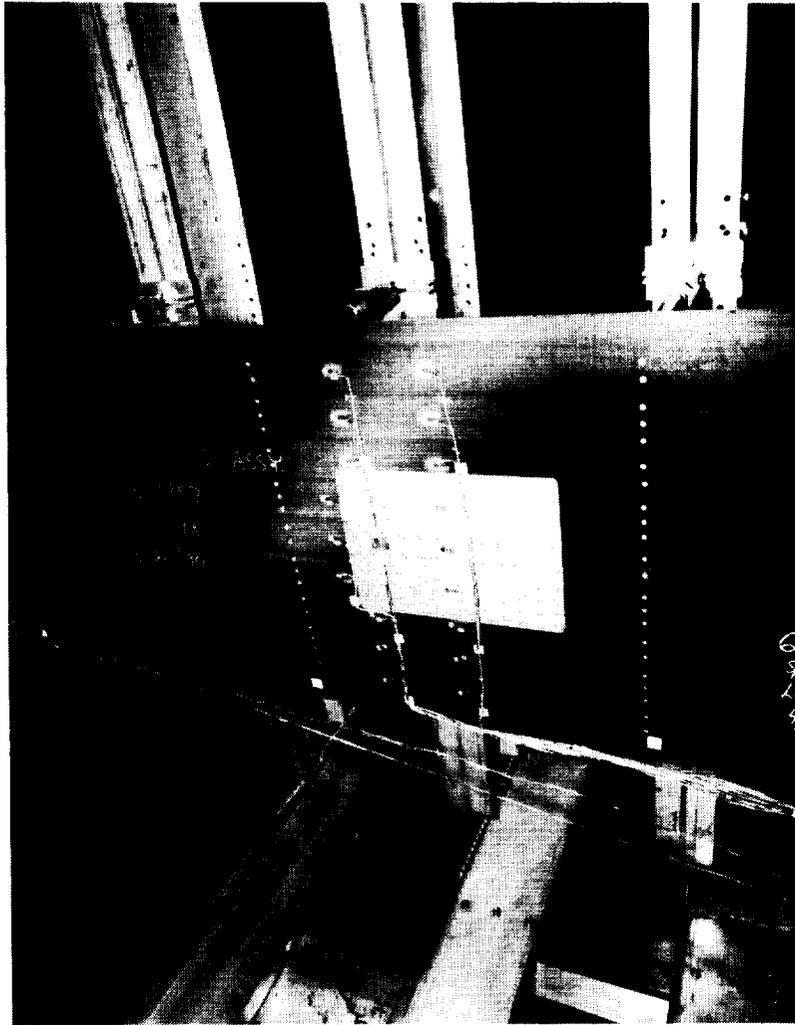


Figure 9

ORIGINAL PAGE
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CFRP Horizontal Stabilizer Test Box Development Test Plan

- Building block approach to design/data development
 1. Material system characterization
 2. Subcomponent tests
 3. CFRP horizontal stabilizer test component
 4. Empennage tests as part of 777 certification
- Integral steps in orderly certification process

Figure 10

**T-TAIL CFRP HORIZONTAL
STABILIZER TEST COMPONENT**

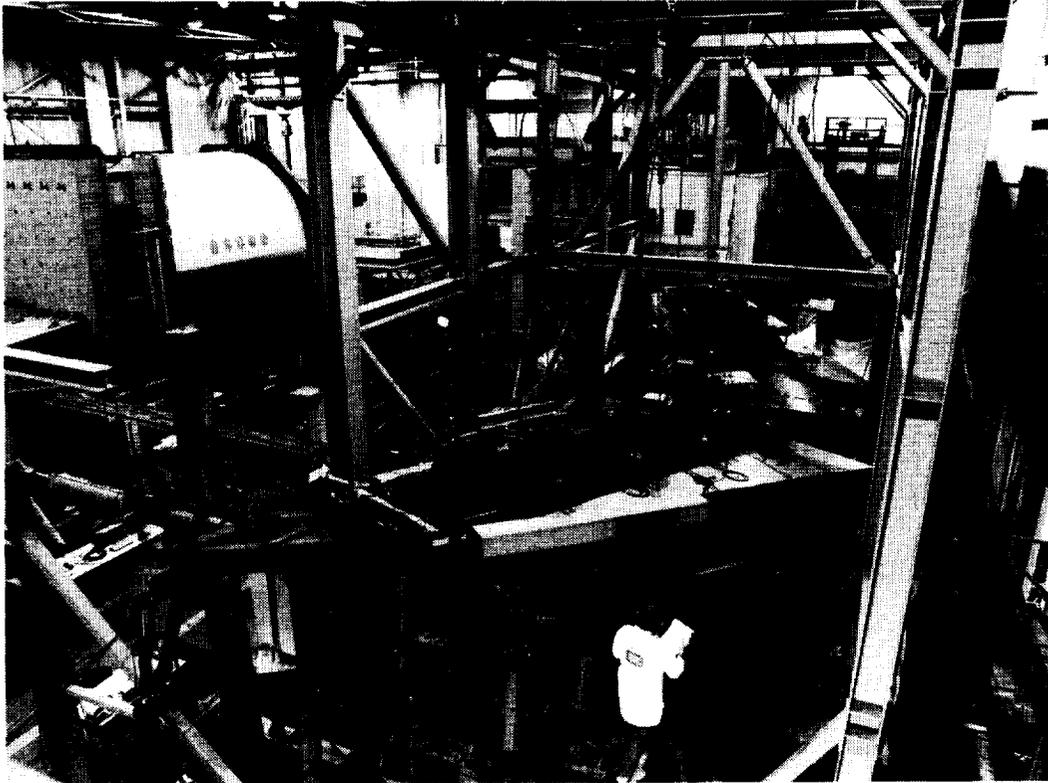


Figure 11

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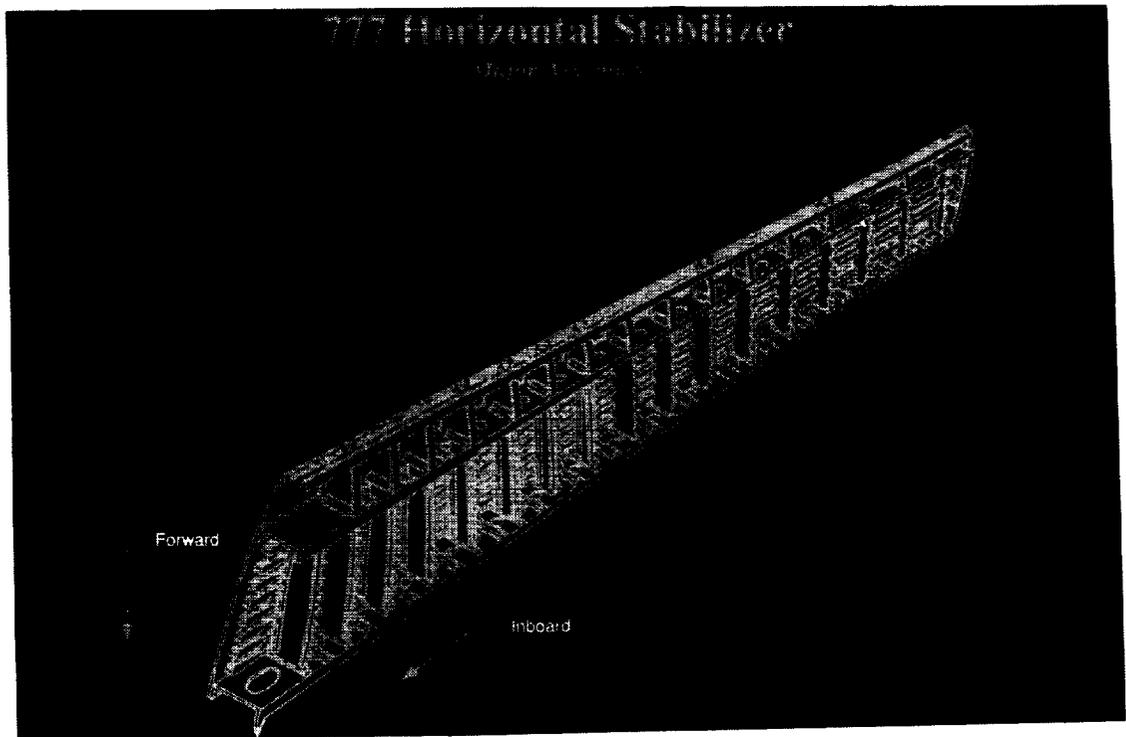


Figure 12

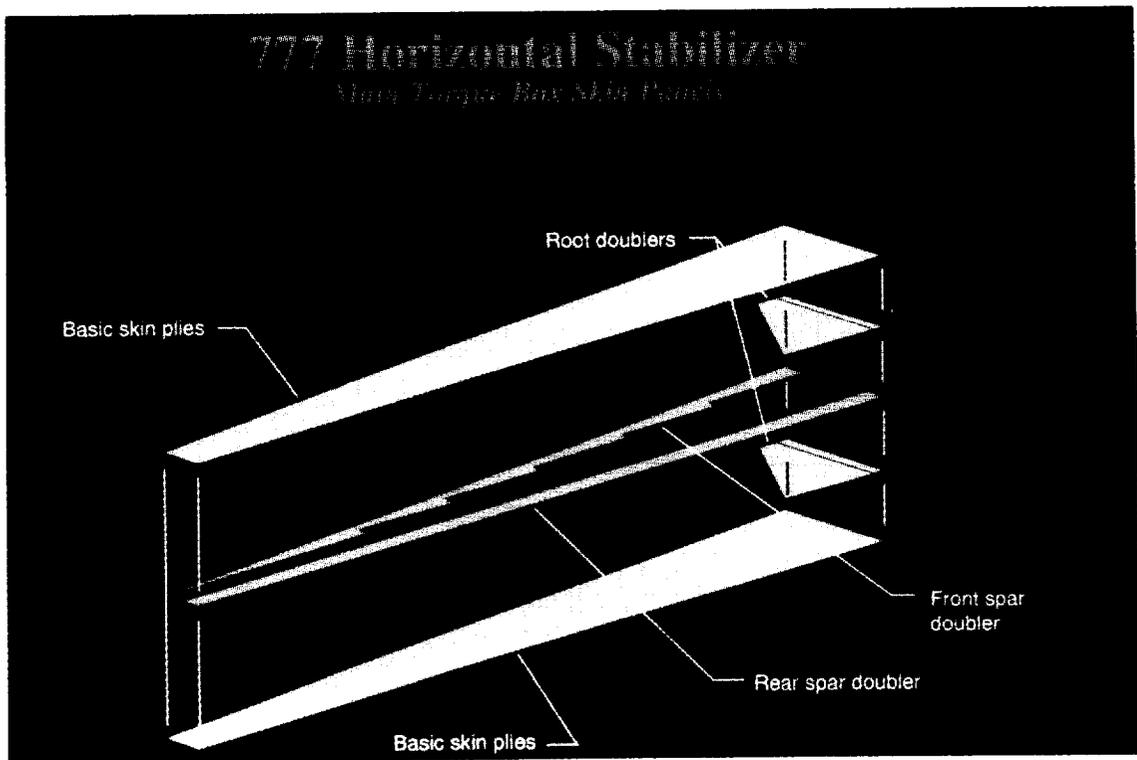


Figure 13

777 Horizontal Stabilizer Rear Spar

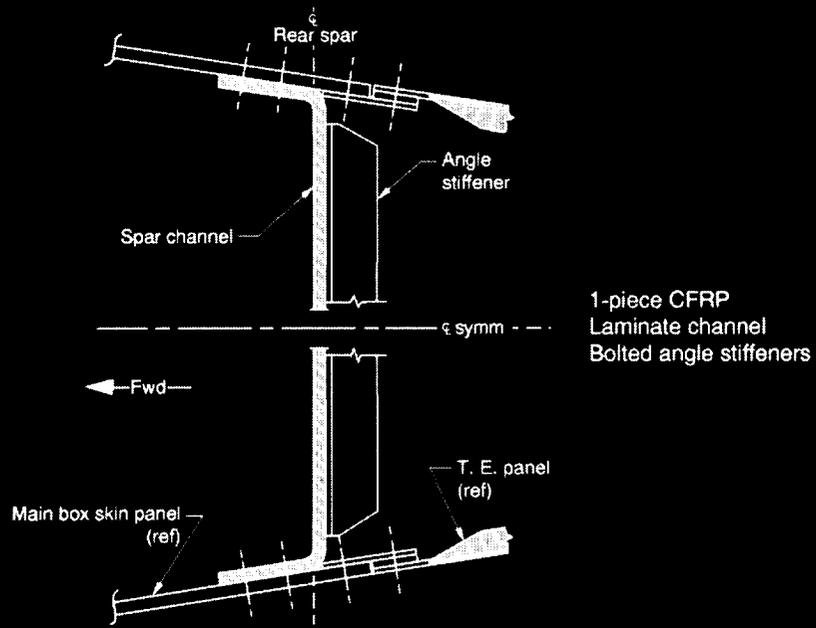


Figure 14

TOOLING

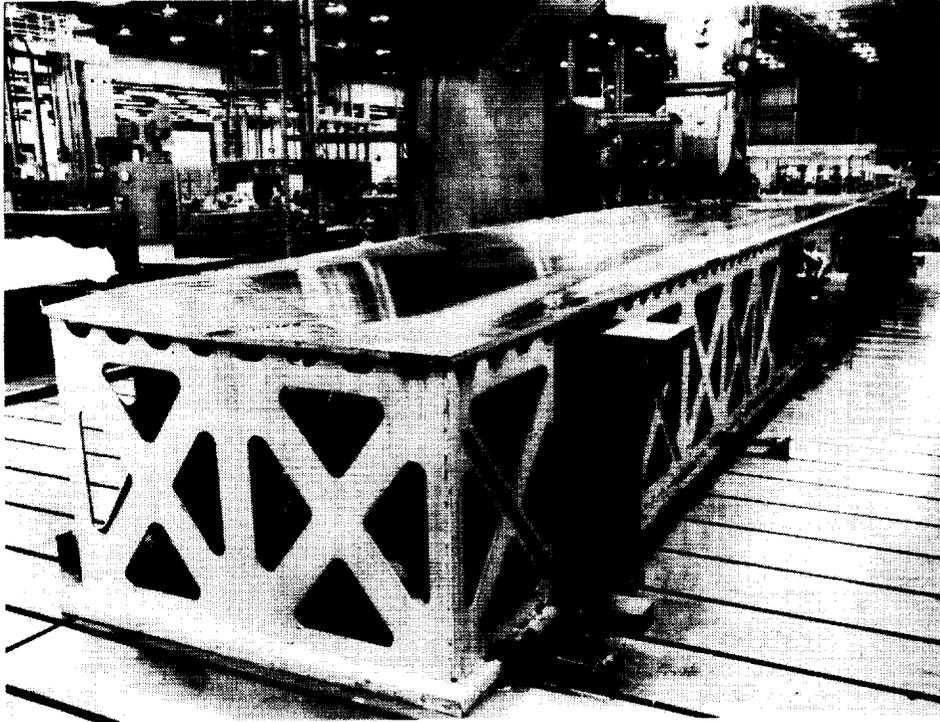


Figure 15
SKIN LAYUP

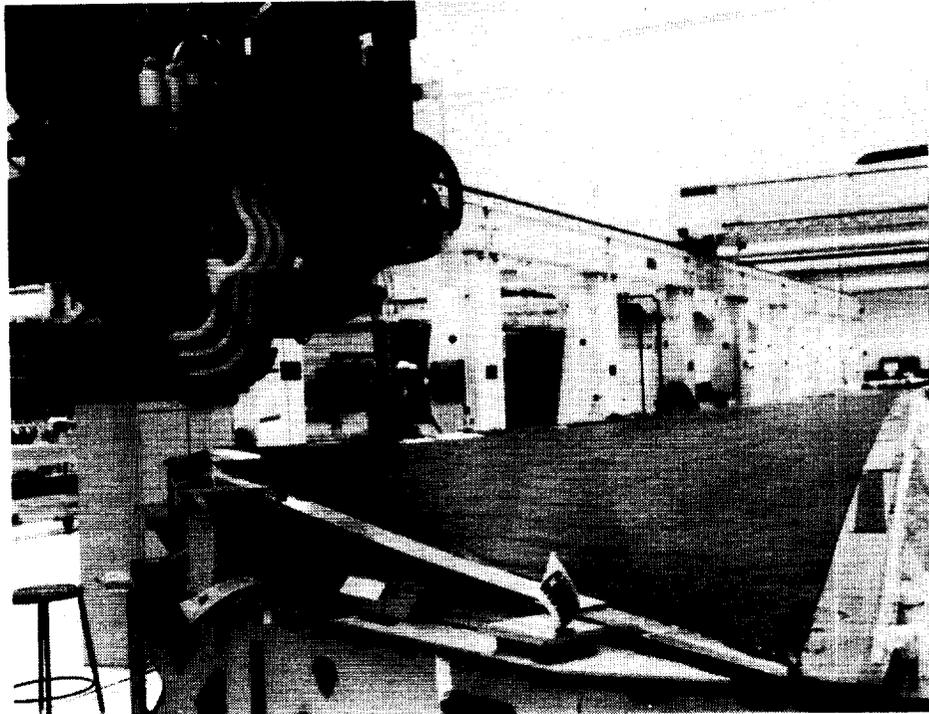


Figure 16

DEMONSTRATION PANEL



Figure 17

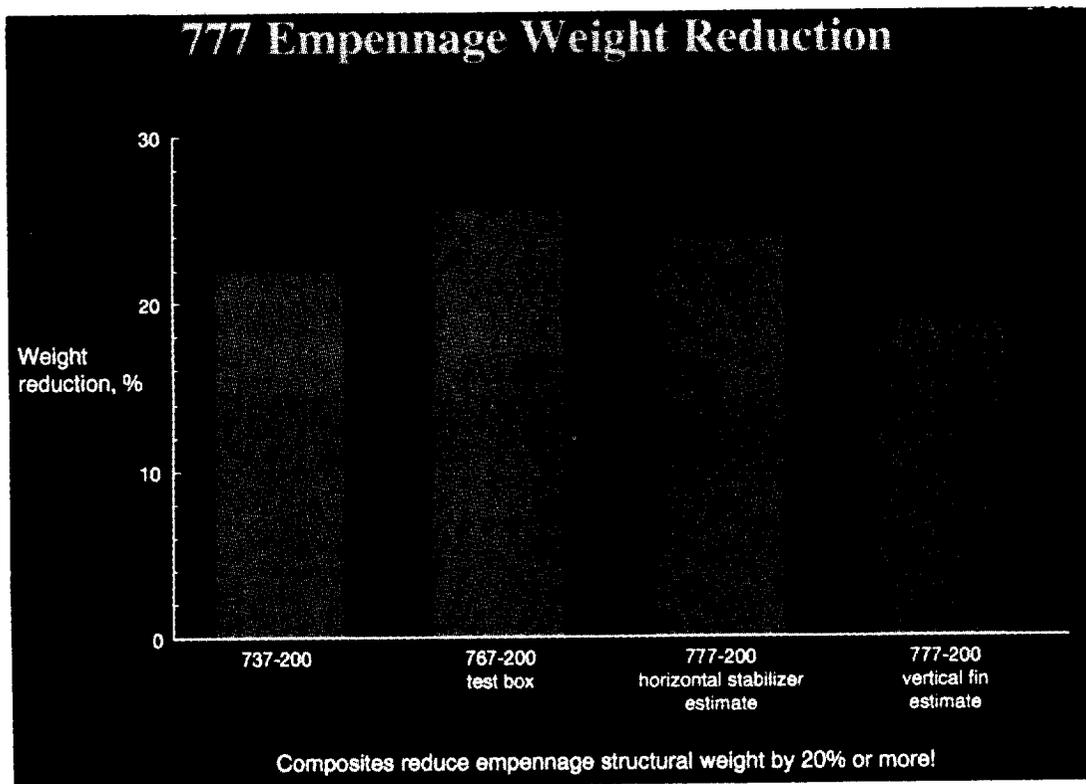


Figure 18

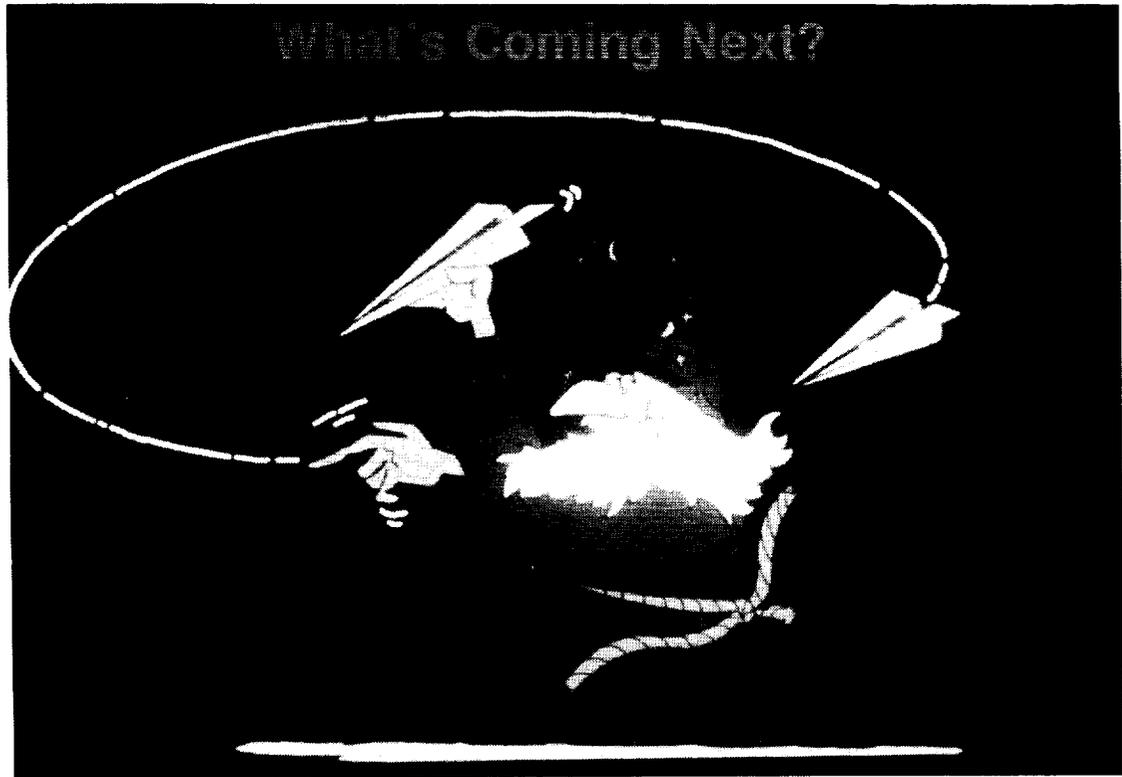


Figure 19

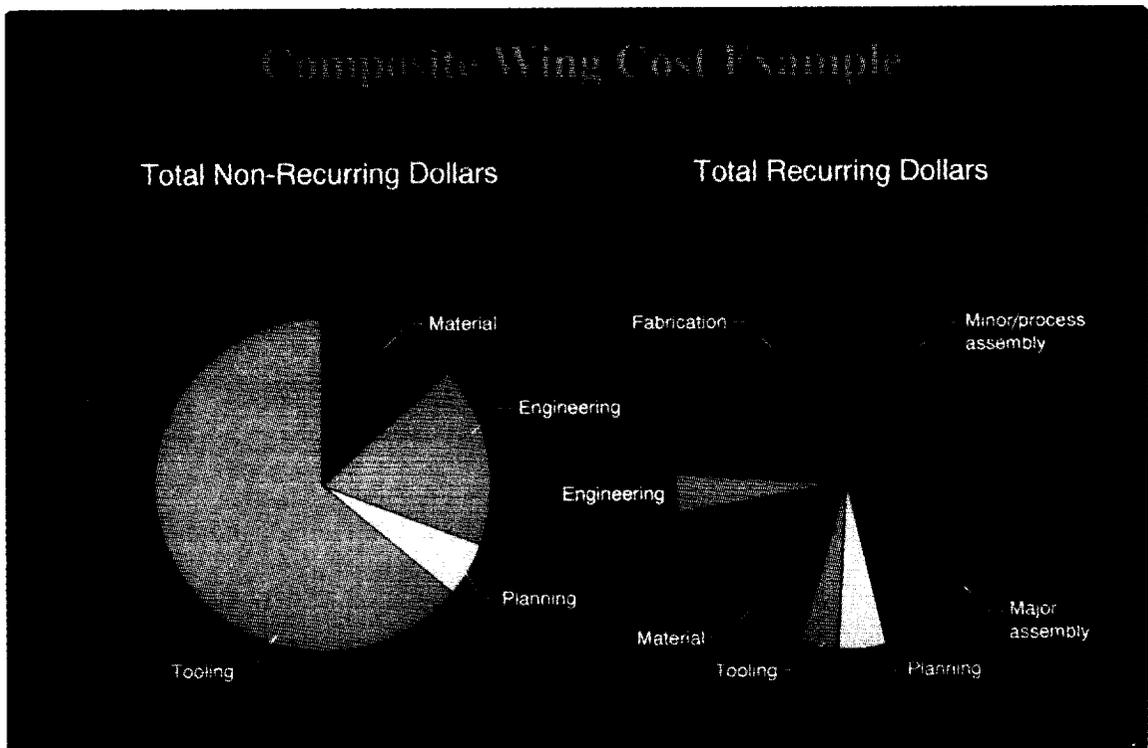


Figure 20

Wing Box Change Versus MTOW Growth Example

Wing Box Change	MTOW Growth	Weight	Strength	Stiffness	Cost	Life
Basic	Base					
Increase MTOW	+6%					
Extended Range	+11%					
Stretch	+11%		A	A		A
Extended Range Stretch	+21%	A	A	B		B
Extended Range Basic	+23%	A	B	C		B
Extended Range Stretch	+27%	B	C	D	A	C

Figure 21

Summary

Composites have achieved:

- Weight reduction
- Corrosion resistance
- Durability

The remaining challenge:

Figure 22

0115

Session II

ADVANCED COMPOSITES TECHNOLOGY OVERVIEW

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